Aerosol optical depth over the mountainous region in central Asia (Issyk-Kul Lake, Kyrgyzstan)

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[1] Aerosol optical depth measurements over Issyk-Kul Lake acquired with the handheld sun photometer Microtops II are analyzed. Aerosol found over the mountainous region at the elevation of 1650 m above sea level resembles mostly clean background conditions. The yearly aerosol optical depth at a wavelength 500 nm $\sim$0.10 ± 0.03 is in agreement with the multi-year means from the background sites of the Aerosol Robotic Network (AERONET). Over a period of 4 years optical depth showed a seasonal pattern, with a maximum observed during summer. A link has been made between new and previously acquired data in order to provide a reliable trend for the region. **Citation:** Semenov, V. K., A. Smirnov, V. N. Aref'ev, V. P. Sinyakov, L. I. Sorokina, and N. I. Ignatova (2005), Aerosol optical depth over the mountainous region in central Asia (Issyk-Kul Lake, Kyrgyzstan), *Geophys. Res. Lett.*, *32*, L05807, doi:10.1029/2004GL021746.

1. Introduction

[2] Knowledge of aerosol characteristics on a global scale, and their temporal change are of great importance for various applications [*Holben et al.*, 2001]. Monitoring of atmospheric turbidity is vital for climate change studies. Improved aerosol climatology enables more accurate estimations of the direct and indirect aerosol forcing [*King et al.*, 1999]. In the last three decades the average thickness of the central Asian (Kyrgyzstan) glaciers decreased by 30% [*Dikikh et al.*, 1999] possibly because of various factors affecting climate (air temperature, change in precipitation, long distance aerosol transport).

[3] Aerosol Robotic Network (AERONET) is a worldwide network of sun/sky radiometers monitoring atmospheric transparency [*Holben et al.*, 1998, 2001]. However, there are neither *WMO Global Atmospheric Watch* [2003] sites nor AERONET sites in central Asia and scarcity of data obtained in that particular area [see, e.g., *Gushchin*, 1988] motivate researchers to analyze and evaluate available information.

[4] Here we present the results of aerosol optical depth measurements over Issyk-Kul Lake spanning a period of more than 4 years, and attempt to link newly acquired optical data with the historical database.

2. Data Collection

[5] Issyk-Kul station is situated in central Asia in the mountains of Northern Tien-Shan along the shoreline of Issyk-Kul Lake (42.6°N, 77.0°E, 1650 m asl). The Issyk-Kul Lake region is surrounded by two giant mountainous chains: Kungey Ala-Too in the north, and Terskey Ala-Too in the south, converging in the west and in the east, and forming the closed area. Some summits in the region are very high ($\sim$5000 m). The Issyk-Kul Lake covers the area of more than 6200 km^2 and lake's surface is located at the elevation of 1609 m above sea level. Mountainous chains, surrounding the lake, hinder the transport of the polluted air from Chu Valley (Bishkek city, capital of Kyrgyzstan) and from the huge industrial center Almaty in neighboring Kazakhstan. Hence, the atmosphere over the Issyk-Kul basin, which has no sources of industrial pollution, can be considered as the background, typical for rural conditions of the central Asia mountainous region.

[6] The Microtops II sun photometer is a handheld instrument specifically designed to measure columnar optical depth and water vapor content [*Morys et al.*, 2001]. The direct sun measurements are acquired in five spectral channels at 340, 380, 500, 675, and 870. The bandwidths of the interference filters vary from 2–4 nm (UV channels) to 10 nm for visible and near-infrared channels. The details

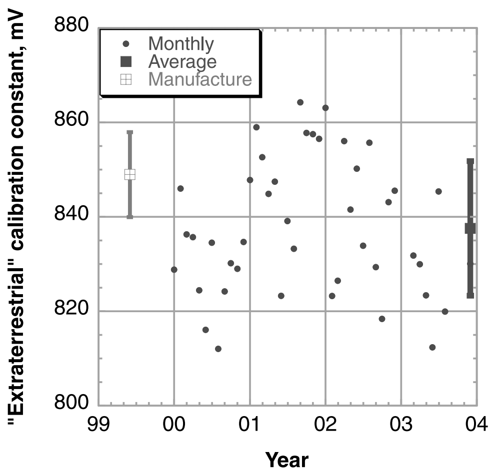

Figure 1. Mean monthly handheld sunphotometer calibration constants at the wavelength 500 nm. The bars indicate plus or minus one standard deviation. Variability in other spectral channels is similar. See color version of this figure in the HTML.

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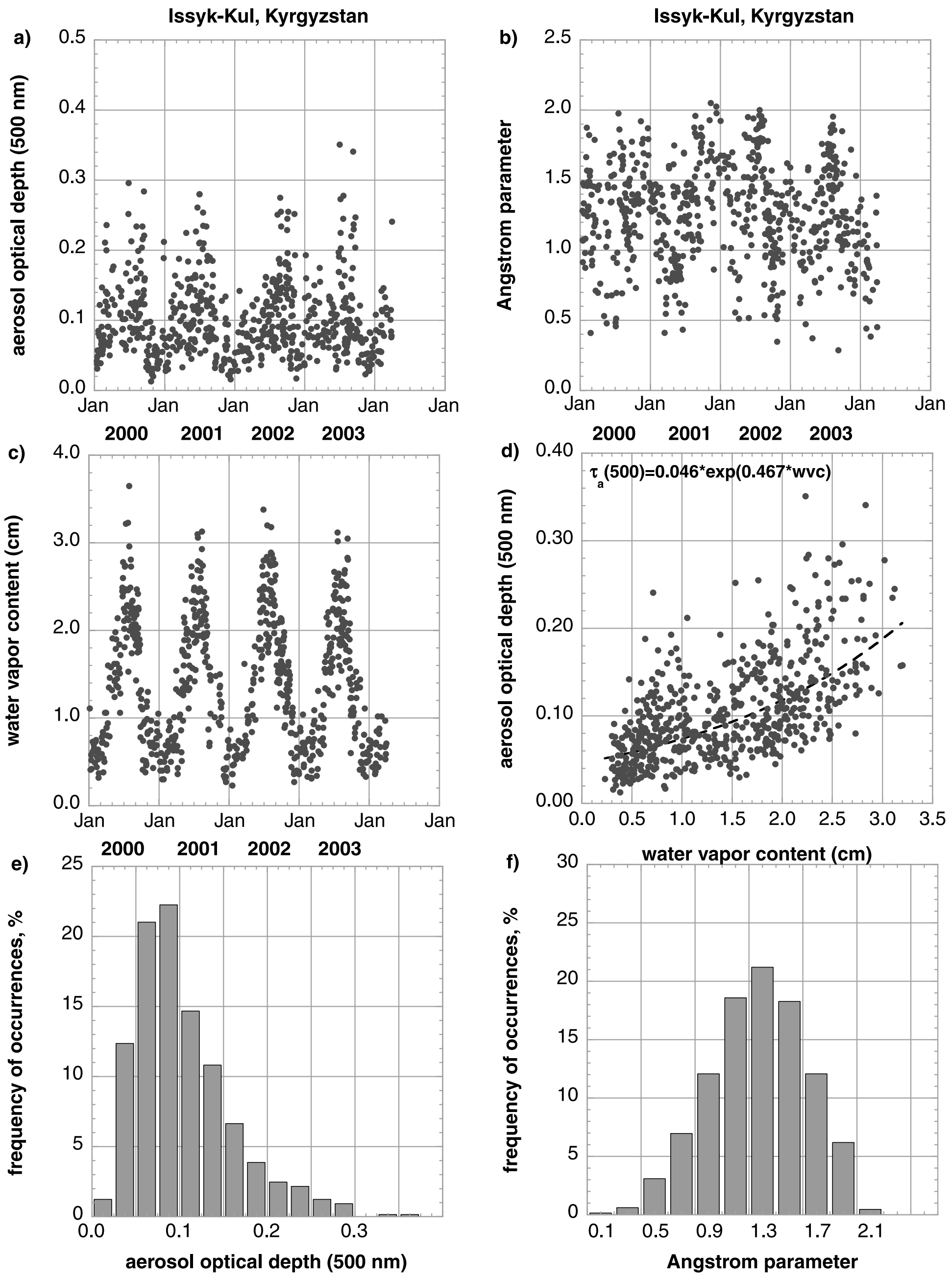

Figure 2. Mean daily values of aerosol optical depth at 500 nm (a), Angstrom parameter (b), and columnar water vapor content (c), scattergram of aerosol optical depth versus water vapor content (d), frequency of occurrence of aerosol optical depth (e) and Angstrom parameter (f). See color version of this figure in the HTML.

of the standard processing algorithm applied and the types of errors involved can be found in the papers by *Morys et al.* [2001], *Porter et al.* [2001], *Ichoku et al.* [2002], and *Knobelspiesse et al.* [2003]. The IR spectrometer [*Kashin et al.*, 2000] has been used for total precipitable water content monitoring.

[7] The measurements have been carried out in a clear weather when the solar disk was free of clouds within the solid angle of 20 degrees (visually controlled by the operator). The number of measurements averaged into one data point was 5. The number of series during the day varied from 3 to 10. Daily average was computed as simple average of data points. We did not consider readings acquired at optical air masses greater than 5.

[8] Reliability of the calibration coefficients can be estimated from Figure 1. It shows the manufacture supplied calibration coefficient, monthly averages of the in situ Langley plots (performed between air masses 2 and 5) [*Shaw*, 1976] and overall average for the measuring period. Calibration constant of a particular month was applied to the available data for the same month. Variation coefficient of the monthly average voltages (which are proportional to optical depth uncertainties) did not exceed ~0.016 and overall uncertainty at 500 nm is 0.02. There is no systematic

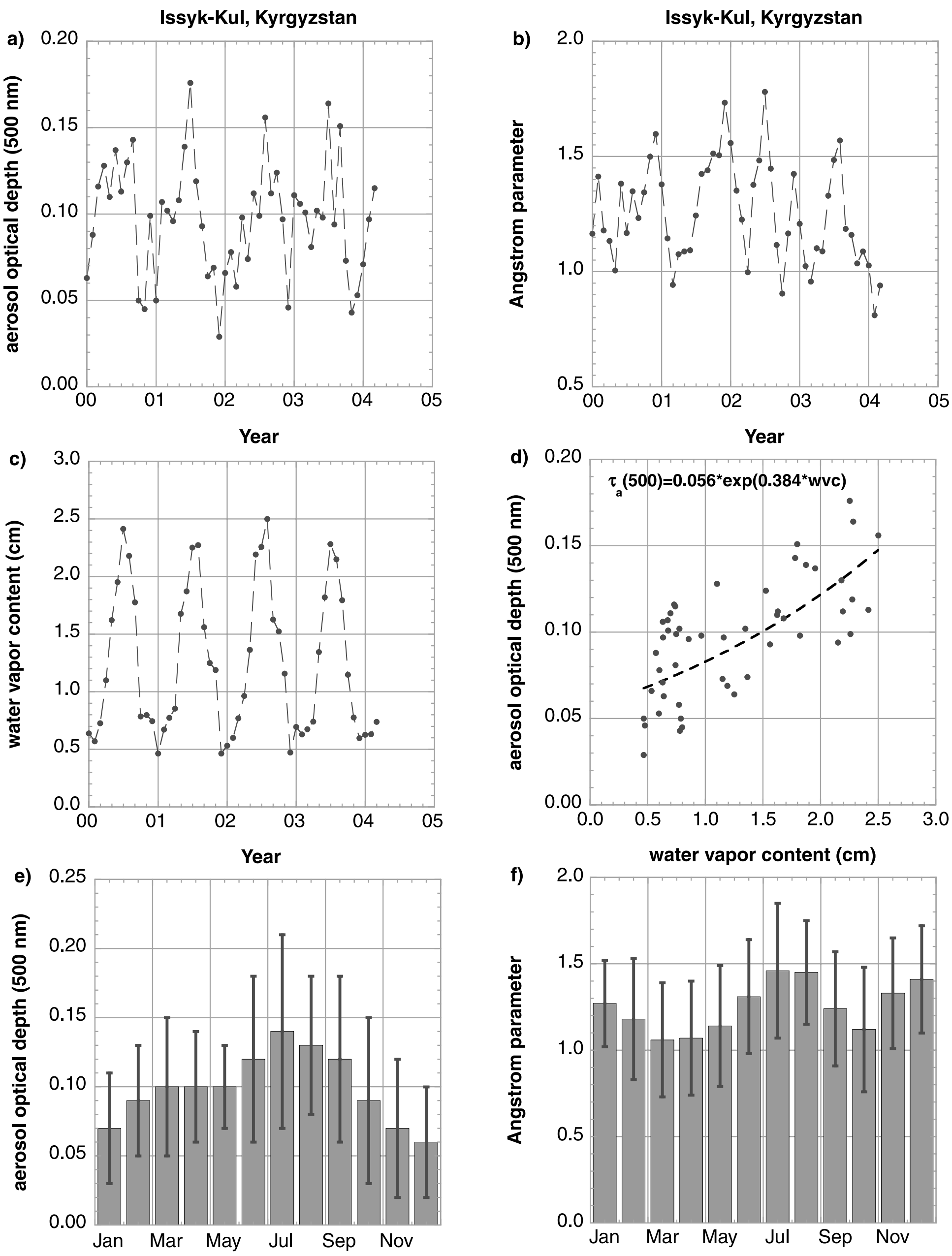

Figure 3. Mean monthly values of aerosol optical depth at 500 nm (a), Angstrom parameter (b), and columnar water vapor content (c), scattergram of the mean monthly values of aerosol optical depth versus water vapor content (d); mean monthly values of aerosol optical depth at 500 nm (e) and Angstrom parameter (f) for whole period of measurements (the bars indicate plus or minus one standard deviation). See color version of this figure in the HTML.

bias in the calibration history and the monthly average differs by 1.4% from the manufacture's calibration.

3. Results

[9] Multi-annual statistics of aerosol optical depth at 500 nm is presented in Figures 2 and 3. A total of 647 daily averages were analyzed (Table 1). The aerosol optical depth shows an increase from May through September, which usually peaks during July. Daily average values of τ_a(500 nm) for all years show moderate day-to-day variation with a summer peak evident (Figure 2a). The values of Angstrom parameter α, estimated within 380–870 nm spectral range (using least-square method), are typically greater 0.5 and less than 1.5 (Figures 2b and 2f). The frequency histogram of τ_a(500 nm) peaks at 0.06–0.08 (Figure 2e), which is typical for the background conditions [*Holben et al.*, 2001]. Columnar water vapor content (*wvc*) shows a distinct seasonal pattern (Figure 2c) and correlates well (R = 0.61) with aerosol optical depth (Figure 2d).

[10] Mean monthly values of τ_a(500 nm), α and *wvc* show insignificant inter-annual variability (Figures 3a–3c). Correlation coefficient of 0.67 between monthly values of τ_a(500 nm) and *wvc* is consistent with the hypothesis of aerosol hygroscopic growth (Figure 3d).

[11] Overall statistics for the measuring period (Jan 2000–Mar 2004) shows gradual increase of optical depth from January to the summer maximum with the following decrease towards the December minimum (Figure 3e). No regular pattern is seen in the mean monthly values of the Angstrom parameter (Figure 3f).

[12] Data collection on aerosol optical depth at the Issyk-Kul station started in 1984 using a photometer with the interference filters [*Aref'ev and Semenov*, 1994]. Since 2000 data acquisition have been continued with the Microtops II. Both instruments were collocated in January 2000 and took simultaneous measurements until March 2000. Daily mean absolute differences for two devices did not exceed 0.02.

[13] The consistency between two data sets allowed presenting long-term record of monthly τ_a(500 nm) over Issyk-Kul Lake starting in 1984 and ending in March 2004 (Figure 4). Over the years the signature of the post-Pinatubo τ_a increase is evident. Yearly average of 0.10 (computed from monthly averages) is consistent with the reported by *Holben et al.* [2001] aerosol optical depths for high elevation background sites (0.08 for Sevilleta, New Mexico; 0.06 for Railroad Valley, Arizona; 0.12 for Dalanzadgad, Mongolia).

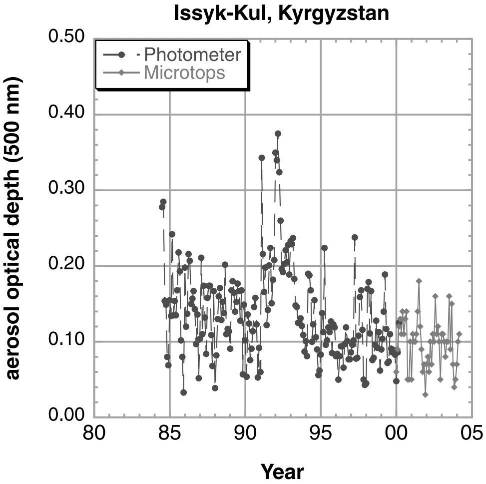

Figure 4. Time series of the measured mean monthly values of aerosol optical depth over Issyk-Kul Lake, Kyrgyzstan. See color version of this figure in the HTML.

Table 1. Database Summary for Measuring Period for Issyk-Kul, Kyrgyzstan (Lat 42.6°N Long 77.0°E, Elevation 1650 m asl), 2000–2004[a]

	τ_a	σ	α	σ_α	wvc	σ	N	Mo.
Jan	0.07	0.04	1.27	0.25	0.59	0.19	47	5
Feb	0.09	0.04	1.18	0.35	0.62	0.16	57	5
Mar	0.10	0.05	1.06	0.33	0.74	0.23	49	5
Apr	0.10	0.04	1.07	0.33	0.92	0.33	31	4
May	0.10	0.03	1.14	0.35	1.54	0.37	54	4
Jun	0.12	0.06	1.31	0.33	1.97	0.46	56	4
Jul	0.14	0.07	1.46	0.39	2.30	0.46	65	4
Aug	0.13	0.05	1.45	0.30	2.28	0.34	87	4
Sep	0.12	0.06	1.24	0.33	1.70	0.48	73	4
Oct	0.09	0.06	1.12	0.36	1.22	0.44	51	4
Nov	0.07	0.05	1.33	0.32	1.01	0.34	45	4
Dec	0.06	0.04	1.41	0.31	0.56	0.21	32	4
YEAR	0.10	0.03	1.25	0.36	1.24	0.64	647	51

[a]Aerosol optical depth at 500 (τ_a), Angstrom parameter (α), water vapor content (cm), associated standard deviations (σ), number of days (N) and months (Mo.) in the observation periods.

4. Conclusion

[14] The results presented show intra-annual dynamics of aerosol optical depth over Issyk-Kul Lake. Atmospheric aerosol optical properties can be considered background for central Asia. Optical depth trend (1984–2004) shows no changes in the aerosol loading in the last 10 years.

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